PTB news
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Technology
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Cooperation
04.3

The world's largest facility for torque calibration

PTB can now calibrate torque transducers in the MN · m range. With the new 1.1 MN · m torque standard machine PTB has measurement facilities to span a range of nine orders of magnitude which can cover almost all of the requirements of industry and research with the necessary measurement uncertainty.

Until now the only place in the world where traceable torque calibrations up to 200 kN · m could be carried out was at the French National Metrology Institute LNE in Paris. The new PTB facility can calibrate torque transducers up to 1.1 MN · m with a measurement uncertainty of 0.1 %. The installation space of this torque standard machine allows transducers for torque greater than 1.1 MN · m to be set up and calibrated in sub-ranges of their nominal range. Today, torque transducers up to 2.5 MN · m are produced.

In contrast to the scale presented by direct loading with masses used up to 20 kN · m the torque in this equipment is produced by means of a double lever arm of equal length with two mechanical spindle drives at its ends in the lower machine platform. The torque transducer to be calibrated is installed vertically in series with a reference torque transducer. The applied torque is measured by means of two tension-compression force transducer pairs which are arranged on a double lever arm on the upper cross-beam section. The design allows to measure the applied torque with almost no disturbing components. The new torque standard machine is under adjustment and testing since May 2004. Calibrations first up to 100 kN · m and successively up to 700 kN · m as well as tests up to 1.1 MN · m have provided proof of-principle and confirm the functional capability of the facility. First calibration orders for industry have already been carried out in this time. Regular calibration operation will start in 2005.

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The new 1.1-MN · m-torque standard machine is currently still in testing yet already in demand by industry. A special torque transducer for a test stand of Siemens Power Generation has been calibrated. This torque transducer will be used for power measurements on heavy gas turbine prototypes for power plants.

Unshielded SQUID current sensors

PTB has developed easy-to-use highly sensitive current sensors with specially designed SQUIDs. Due to their high robustness they can be operated in interfering magnetic fields of the same order of magnetitude as the earth's field. Therefore, they are suitable for a wider range of technical measurement tasks.

SQUIDs (*S*uperconducting *QU*antum *I*nterference *D*evices) are generally applied for very sensitive magnetic-field measurements. They can also be used to measure smallest electrical currents in an excellent manner. They are outstandingly suited as pre-amplifiers for specific types of radiation detectors, such as micro-calorimeters or superconducting hot-spot-detectors, which – like the SQUIDs themselves – are operated at temperatures at or below liquid Helium temperature (4.2 K).

In a project funded by BMWA (German Federal Ministry for Economy and Labour) PTB has developed SQUID current sensors together with Vericold GmbH in Ismaning, and Magnicon GbR in Schenefeld. The new devices are specifically designed for applications in energy-dispersive x-ray spectroscopy. However, they can also be used for other technical measurement tasks, such as realization and dissemination of electrical units.

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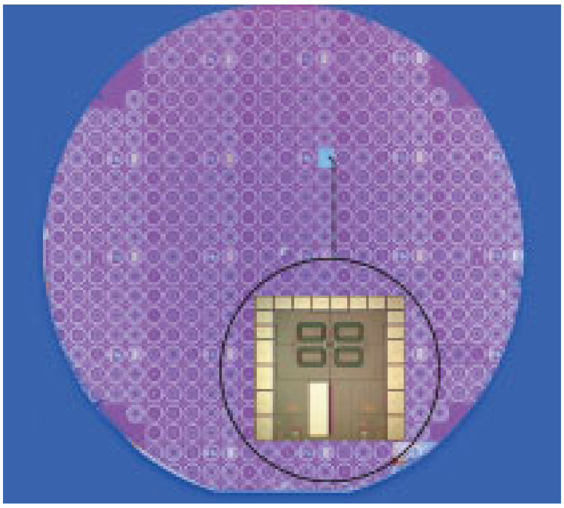
Unshielded SQUID current sensors (*continued from page 1*)

Usually, in a SQUID operated as a current sensor the current to be measured is fed through a coil. The coil is aligned so that its magnetic flux penetrates the SQUID. PTB has achieved excellent noise levels (<1 pA/√Hz for frequencies above 1 kHz) with this type of current sensors.

The circuits used for these devices were made using Niobium as superconducting material, produced by multilayer technology with structural widths of 2.5 mm. Recently, the first current sensor based on a new interference-insensitive design was tested successfully. Due to the gradiometric design and in spite of their high sensitivity these sensors can be cooled down unshielded in interfering magnetic fields with amplitudes in the order of the earth's field (approx. 50 mT) and can be operated without degradation of their characteristics or current noise. Furthermore, the sensors can be mounted directly on to massive copper substrates, which usually lead to higher noise, without deteriorating their parameters. Such a mounting enables a good thermal contact down to milli-Kelvin temperatures and simplifies the cryogenic setup. In the latest version up to 16 SQUIDS are connected in series to increase the dynamic range.

The simultaneously furthered development to improve the electronics used to read out the sensors aims at extending the bandwidth from presently 5 MHz to 20 MHz. Interested users can acquire the new current sensors commercially through the company Magnicon GbR. The company also produces the PTB electronics under license and distributes them.



3" wafer with ca. 400 current sensor chips. Inserted is a magnified close-up of a single chip.

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Illumination of magnetic resonance images

PTB has developed a 4-channel array coil for 3 tesla magnetic resonance (MR) imaging. The radio frequency (RF) transmit/receive array coil operates in a coherent mode and can actively control the RF magnetic field distribution in the investigated body region to produce more uniform MR images in high and ultra-high field MR scanners.

In present magnetic resonance systems for medical imaging a radio frequency magnetic field B_1 is superimposed with a static magnetic field of up to 3 tesla. The trend is to go to much higher static magnetic fields of 7 tesla and more to increase sensitivity and resolution. To image the water protons in the human body the RF magnetic field B_1 with frequencies between 125 MHz (3 tesla static field) and 500 MHz (11.7 tesla) is applied by a resonant coil system. In the human body the wavelength of this RF radiation is reduced to some 10 cm because of the high dielectric permittivity of water. This gives rise to wave-like propagation phenomena, which lead to severely degraded illumination uniformity in the MR images and so partially deteriorate the desired increase in sensitivity of ultra-high field MR systems.

A coherently driven assembly of several transmit/receive coils (TR-arrays) can alter and control the distribution of the RF B_1-field within the human body. This requires that the individual coil elements are driven with adequate amplitudes and RF phases. Based on this principle PTB in cooperation with Bruker Biospin MRI developed a 4-channel TR head coil and established a measuring technique to determine the B_1-field distribution. This project was funded by BMWA (German Federal Ministry for Economy and Labour). Further, the B_1-distribution and the specific absorption rate (SAR) in a human's head are determined in model calculations. The SAR must not exceed legal limits to protect patients from overheating. The numeric model is validated by comparison with phantom measurements. The driving conditions for the coil array is determined by the simulation calculations which yield the most homogenous distribution of the B_1-field in the body and guarantee the highest patient safety.

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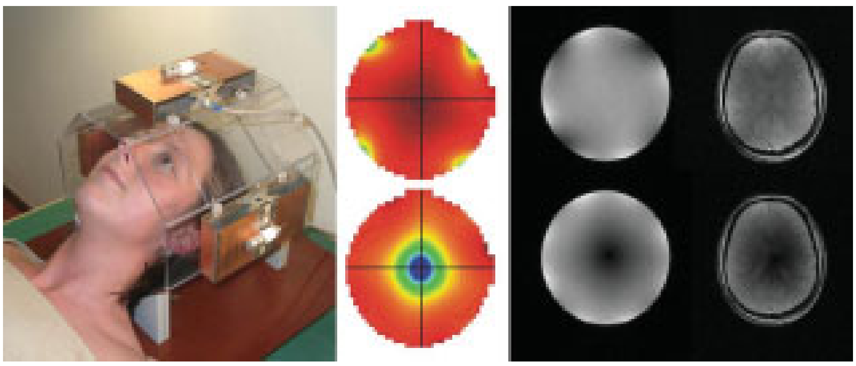


The new 4-channel head coil (l.) with B_1-field distributions calculated for different control settings (above: "homogenous" operation mode, below: "Donut"-operation mode) and the corresponding MR images in a phantom and in vivo, respectively.

Light microscope measures nanostructures

PTB has developed two procedures that enable detecting structures as small as one hundred nanometres with a light microscope, thus well below the classical resolution limit.

Many fields of natural sciences and technology are using ever smaller structures with dimensions in the micro- to nanometre range. Therefore, there is a need to determine the geometric lengths of these structures, for instance, to assess the functionality of microelectronic components. Light microscopic measurements are simple, fast and inexpensive. However, if the dimensions of the structures to be measured are of the same size as the optical wavelength applied, then "proximity effects" pose a problem. In that case diffraction patterns superimpose and interfere with the structural features.

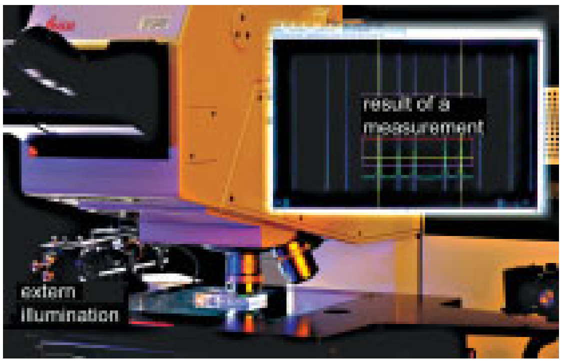
At PTB it has been demonstrated that these effects can be significantly reduced by illuminating structures under grazing incidence and by changing the direction of the incident light. By illuminating with a laser of appropriate polarisation in one direction light is primarily scattered by structural edges facing the direction of the impinging light. By changing the direction of the light one can selectively switch between diffraction patterns of the rising and falling edges and one can measure them separately in a time-resolved mode.

Based on this principle two (dark field-) microscopic methods have been developed. Both procedures allow highly precise measurements of structures well below the classic resolution limit for light microscopy. In due course the measurement uncertainties could be reduced from 50 nm to 20 nm.

In the first method, AGID-microscopy (alternating grazing incidence dark field microscopy), the structure to be investigated is illuminated by incident light (reflection mode), whereas in the second method, FIRM (frustrated total internal reflection microscopy), the illumination occurs in transmission. To achieve this special optics had to be realized to couple the light into the substrate of the sample.

Both methods have already been picked up by industry and are to be applied in the field of inspection systems for photo-masks in the semiconductor industry as well as to characterise structure sizes in nano- and microparticles.

At the time being the technology is under further development within a joint project with an industrial partner. Goal of the project is to provide users improved measuring systems that will allow linear measurements of structural widths down to 100 nm using light of a wavelength of 375 nm. Compared with conventional bright-field microscopes with the same wavelength this constitutes an improvement by a factor of two.



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Measurement facility for smallest forces

The increasing miniaturization in micro-engineering and nanotechnology calls for dimensional measurement techniques with traceable contact forces in the mN range and lower. PTB has built a micro-force-measurement facility for the 1 mN to 5 N range. Via a modified compensation balance the new set up links up with the mass scale.

The measurement system uses (1.) a piezo-electrically adjusted fine displacement to create a minute force and (2.) a modified electromagnetic compensation balance to trace it back. The force transducer to be investigated is positioned between the balance and the fine displacement assembly. By varying the piezo-electrically induced displacement different load progressions can be generated and traced. The transducer output is compared with the calibrated balance signal.

The entire displacement possibly provided piezo-electrically is 100 μm. In order to make the most use of that range several modifications were carried out on the balance. They were aimed to minimize the load-dependent lowering of the contact position. Due to the finite rigidity of the lever mechanism in the balance an introduced force of 5 N induces a lowering of some 4.5 μm as determined interferometrically.

Measurement operation runs force-controlled on the signal of the force transducer to be measured. Deviations from linearity between the recorder values, the created and measured force values of the measuring device lie within ±5 digitalisation steps of the transducer amplifier. Possible interactive influences between transducer and measuring device are collected by means of a rotating table, – rotating around its own force axis – and taken into account by averaging. The relative measurement deviation from the calibration of the transducers in

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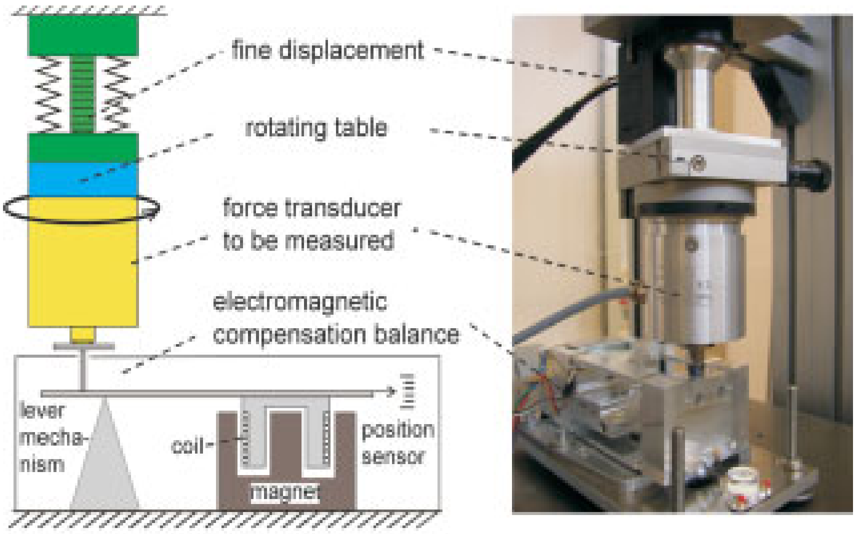
Measurement facility for smallest forces *(continued from page 3)*



the 200-N force standard facility at PTB in the range of 1 N to 5 N lies below $5 \cdot 10^{-4}$.

The modular set-up of the measuring facility will make it possible to extend the scale into the mN-force range by applying more precise laboratory compensation balances.

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Are fundamental constants really constant?

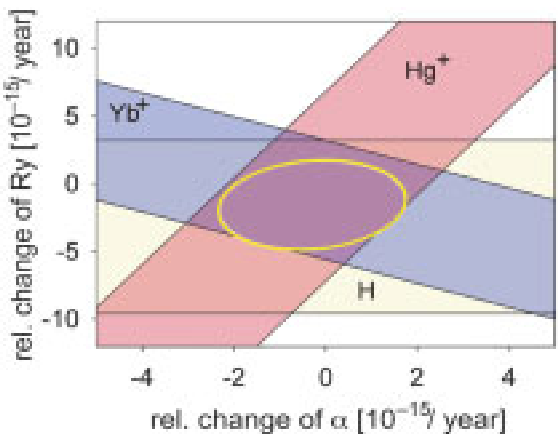
The discussion about possible variations of fundamental constants was excited in recent years because astrophysical observations seem to indicate a significant change in the value of the fine structure constant, a, around 5 - 10 billion years ago. PTB engaged in a search to detect a possible variation of a and carried out a precise comparison of different atomic frequencies over a period of three years. The result excludes a present day variation of a larger than a relative change of $2 \cdot 10^{-15}$ per year.

The postulate of the constancy of fundamental quantities – like, for instance, the speed of light – is basic to how physics describes the universe and, therefore, is decisive for metrology. It must be experimentally verifiable. New theoretical models for a unified description of the fundamental interactions of physics indeed allow such variations or even describe them as indispensable.

The most important test case is the so-called fine structure constant, a, a dimensionless number composed of the speed of light, the elementary charge and Planck's constant. It appears in the description of several atomic and electric phenomena. By comparing atomic clocks based on different atomic transition frequencies a very precise test of the constancy of a can be carried out: if a changes in time, the clocks will increasingly drift out of synchronism as a effects the different atomic transition frequencies each in a specific manner.

At PTB an optical frequency standard based on a trapped ytterbium ion was compared to the primary caesium atom clock CSF1 ("fountain-clock") twice over an interval of three years. Within the combined uncertainty, the two measurements agreed very well. The frequency of the optical standard had not changed in comparison to the caesium clock. Similar results were obtained during 1999 to 2003 by NIST (Boulder, USA) for the optical frequency of a trapped mercury ion and – in a collaboration between MPQ (Garching) and BNM-SYRTE (Paris) – in an investigation on atomic hydrogen.

The combination of these results allows a clear conclusion on the constancy of a. Should there have been dynamic changes of the fundamental constants in the early stages of the universe they have obviously decreased in our time to the point that they are below the detection limits of the best available precision measurements.



The diagram shows the results of the measurements of transition frequencies in Yb and Hg ions and in the H atom (with their respective 1 s uncertainties). The relative change in the Rydberg frequency (Ry) is plotted as a function of the relative change of the fine structure constant, a. Since the point of origin of the diagramme, where Ry and a are strictly constant, still remains within the area of "combined uncertainty" (central ellipse), the measurements do not indicate a change in Ry and a.

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